Minimum Bias Pileup
and
Missing Et at CMS

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Introduction

The missing Et trigger was constructed by the UA1 experiment in recognition that a "hermetic" detector could trigger on produced neutrinos by asking for an imbalance in the transverse energy in the final state [1].

Clearly, the ability to trigger on missing Et implies that the effects of neutrinos dominate

The azimuthal angle was chosen uniformly. The polar angle was chosen such that the rapidity of the pion was uniformly distributed for |y| < yo and which was distributed as a power law decrease from yo to zero at the kinematic limit y_{max}. For an incident proton momentum of po, the maximum pion, mass m, rapidity is po ~ $m_t \sinh(y_{max})$ where $m_t^2 = m^2 + Pt^2$. In this note, a linear falloff in rapidity was used, although other dependencies were examined. The rapidity distribution had 2 adjustable parameters, the value of yo and the power law falloff behavior. The single particle distribution is given in Fig.2.

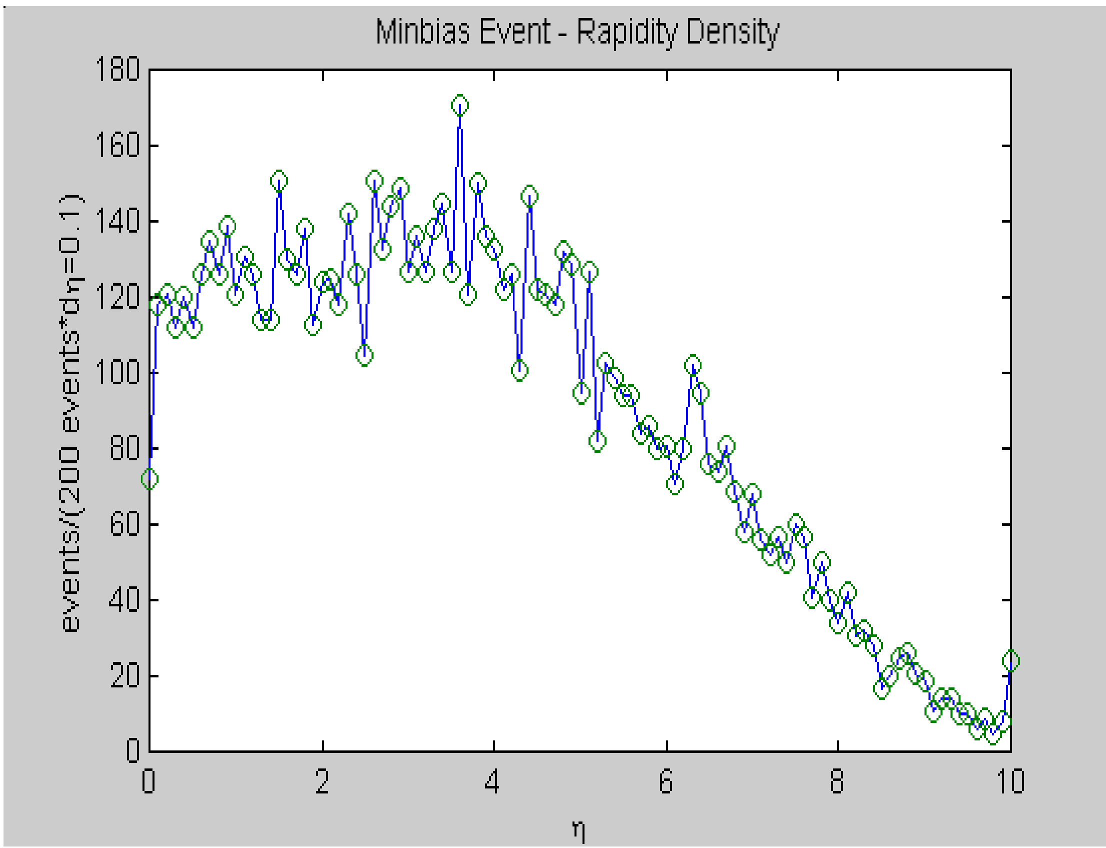

Figure 2: The single particle rapidity distribution for secondary pions. Note the rapidity “plateau” for |y| < 5 and the linear falloff to the kinematic limit.

Note that the single pion distributions follow the inclusive distributions seen in hadron collider experiments [3]. In fact, one body relativistic phase space, without kinematic limits, is $d^4P\delta(p*p - m^2) \sim dPxdPydPz/E \sim dydPt^2$. Therefore, a uniform rapidity distribution is simply a statement that we pick from a single particle phase space distribution.

The model for a minimum bias event was extremely simplified. Basically, there were no correlations. Pions were picked from the inclusive distributions in Pt and y. The "generation" of pions continued until all the initial state energy and momentum were consumed. The last pion was chosen to exactly conserve the 3 components of momentum. Energy was not explicitly conserved.

The resulting pion multiplicity is shown in Fig. 3. The mean is <n> ~ 88 or ~ 59 changed pions in the event on average. Comparing to a compilation of data at lower energies [4], this value for the mean multiplicity is quite reasonable

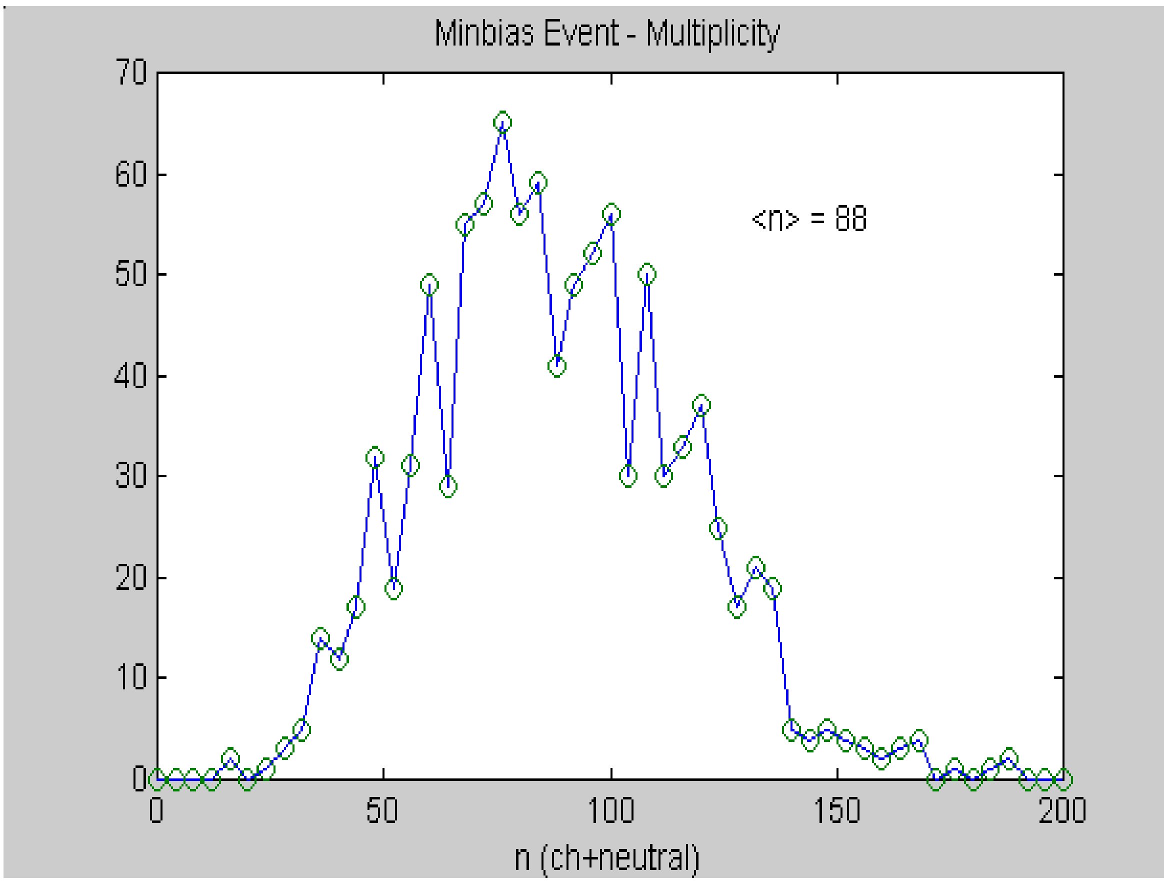

Figure 3: The total charged plus neutral pion multiplicity in a minbias event. The mean multiplicity is, <n> = 88.

The density of particles in rapidity space can be extracted from Fig.2. For all particles it is ~ 6 particles per unit of rapidity on the plateau. Therefore, the density of 4 for charged particles is obtained. This value is reasonable [3] assuming a ln(s) behavior in extrapolating data from lower energies.

The resulting minimum bias event is shown in a "lego plot" in Fig.4. The cell sizes are those appropriate to the CMS hadronic calorimeter which has 72 divisions in azimuth and covers out to |y| = 5 in pseudorapidity with ~ "square" cells in η and φ.

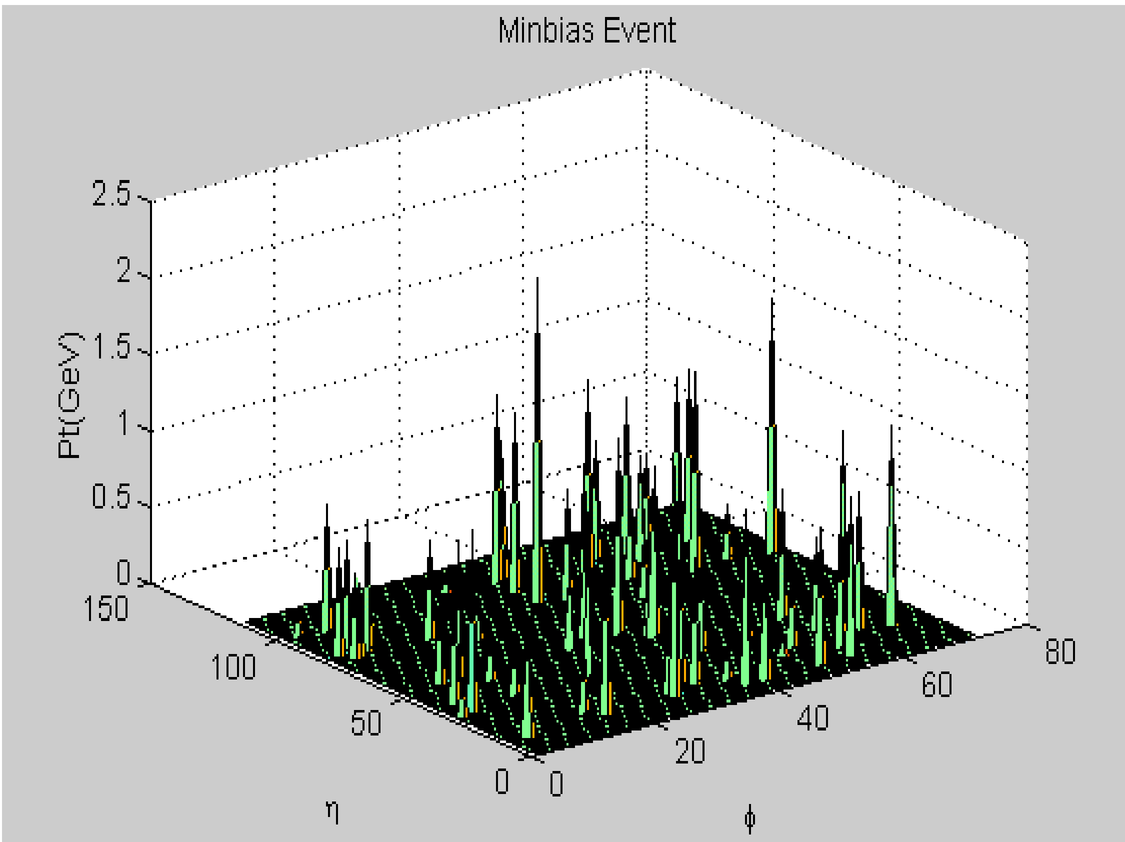

Figure 4: Lego plot for a single minimum bias event for the CMS HCAL. The (x,y) axes are (η φ), and Pt is the vertical axis.

Note that in a single event with n ~ <n> ~ 88, there is 66 GeV of total transverse energy, on average. If the total Et were distributed statistically, one might expect ~ 8 GeV of Et in a minimum bias event.

Monte Carlo for Pileup

The beam bunch crossings are populated by a number of minimum bias events which are Poisson distributed and , for a given luminosity, characterized by a mean number of minimum bias events per crossing. For this study, a fixed number of events was put into a crossing, in order to cleanly isolate the effects of a given number of events per crossing.

The distribution of the total Et for a crossing when there was one and only one event per crossing is shown in Fig.5 The mean transverse energy is <Et> ~ 5 GeV. There are 2 major contributors to this value. First, the single particle energies are smeared by a parameterized calorimeter resolution as, $dE = a\sqrt{E}$, where a = 1.0 with E in GeV. Second, the calorimetric coverage is truncated at $|y| < 5$ as is the present CMS design. Note that, from Fig. 2, a substantial fraction of the pions falls outside the CMS coverage. In the simple model used here, with no short range correlations, the effect of truncation of angular coverage is comparable to that of calorimetric energy resolution in inducing a spurious total transverse energy into the event. Therefore, even perfect calorimetric energy resolution would not substantially alleviate the effects of pileup in the context of the present model. Note also that the effects of magnetic field, e.g. “loopers”, have not been taken into account in the present treatment.

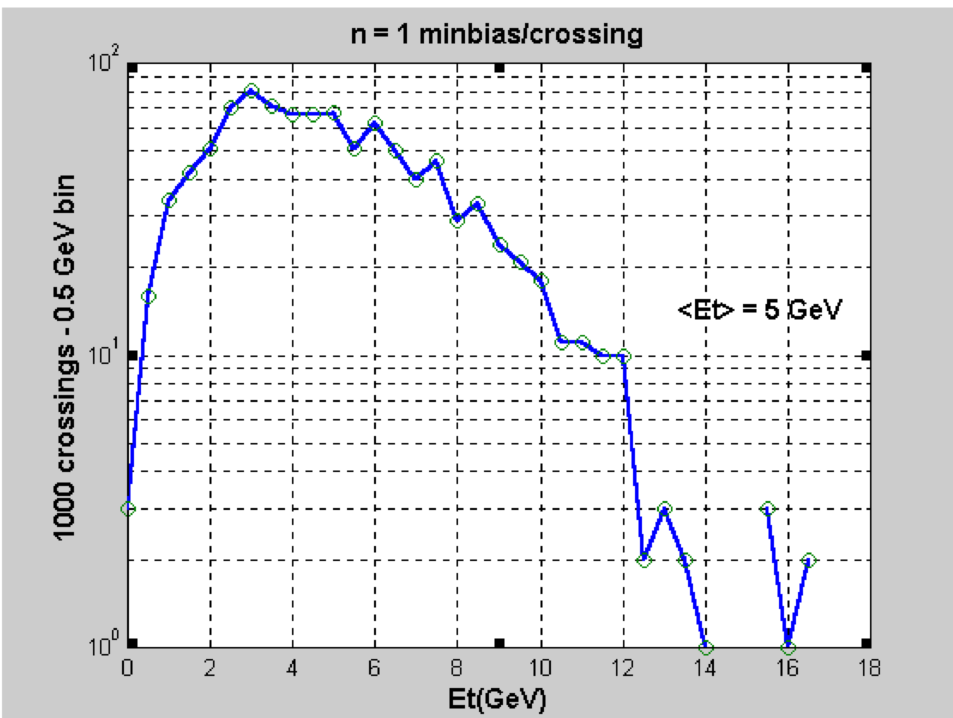

Figure 5: Distribution of Et for a crossing containing one minimum bias event. The mean is <Et> = 5.0 GeV.

Note that there is a > 1 % chance to have > 12 GeV of "missing energy" in the crossing due simply to fluctuations in a single minimum bias event. If we take the inelastic cross section to be 100 mb, then there is effectively a 1 mb trigger cross section for "neutrinos" with transverse energy > 12 GeV.

The total transverse energy in a crossing is a global variable. As such, the fluctuations in transverse energy are difficult to calculate analytically, $Et = \sqrt{(\Sigma E_{xi})^2 + (\Sigma E_{yi})^2}$. The result of propagating the errors due to energy resolution does not lead to a transparent expression. Suffice it to say that $dEt \sim a/\sqrt{Et}$ is a rough estimator of the effect of energy measurement errors. Taking Et ~ 88 GeV per event, we estimate dEt ~ 9 GeV, which is at least comparable to the observed mean of 5 GeV. Note, however that energy measurement is not the predominant contributor to Et.

The mean value of Et for a crossing as a function of the number of events in the crossing is shown in Fig.6. Note that the scaling as $\sqrt{n}$ appears to hold, as would be expected on statistical grounds.

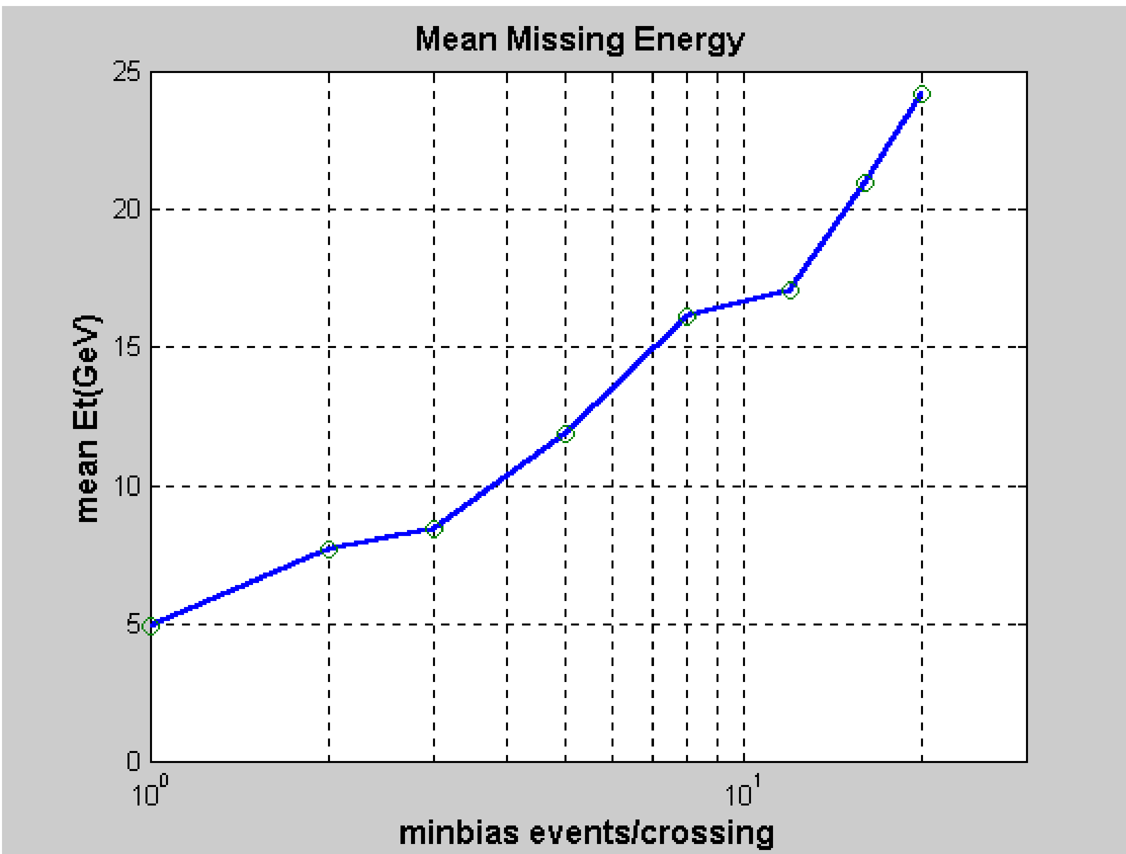

Figure 6: Mean Et per crossing as a function of the number of minbias events per crossing. The basic functional dependence is $\langle Et(n) \rangle \sim 5.0\ \mathrm{GeV}\sqrt{n}$.

One strong indication that the behavior of the Et of the crossing is not naively statistical, is that the r.m.s. of the Et distribution divided by the mean, $\sigma/\langle Et \rangle$, is roughly constant for from 1 to 20 events per crossing with a value of ~ 50%. This behavior is seen in D0 Run I data [5] also.

The probability for a crossing to have an Et above thresholds of 20, 30 and 40 GeV are shown in Fig.7 for numbers of events per crossing from 2 to 20. Note the rapid rise with n. The behavior is very approximately a rise as n^3. Note that with 20 events per crossing, the total particle Et in the crossing is ~ 1.32 TeV, with a naïve statistical fluctuation of 36 GeV.

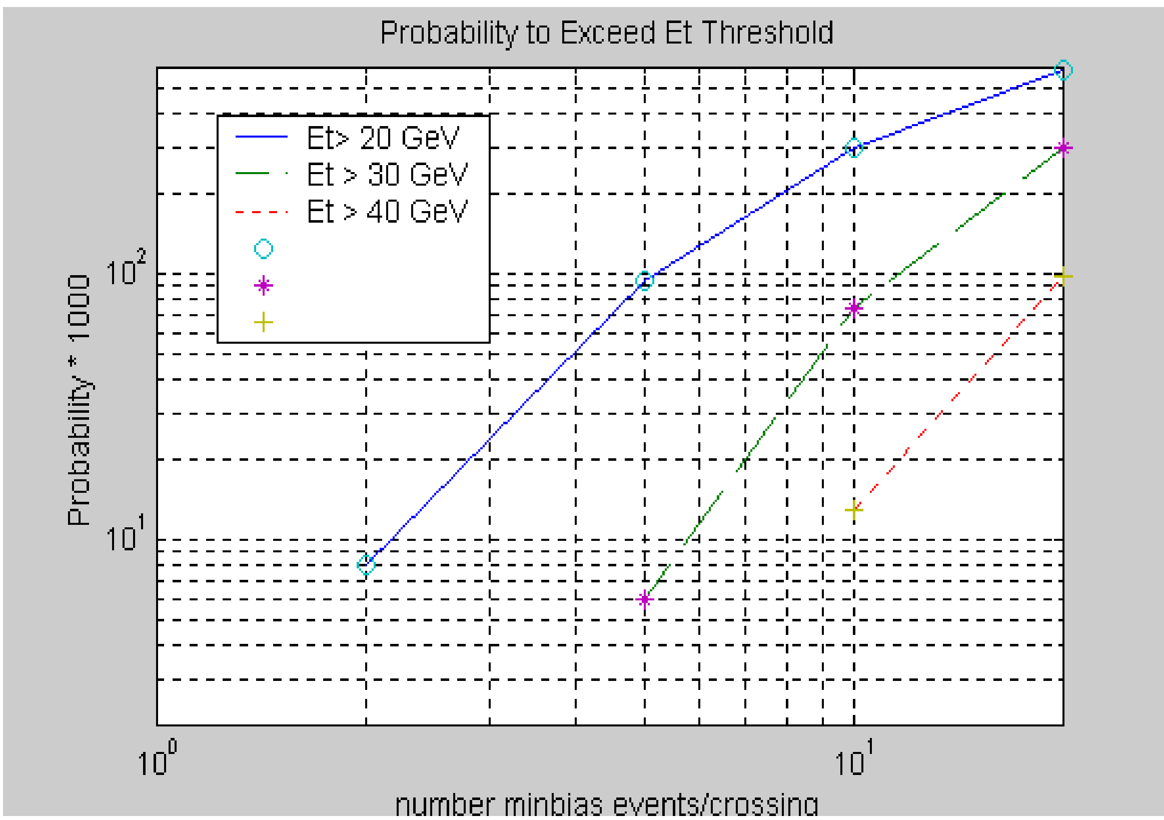

Figure 7: Probability for a crossing to have a total transverse energy above a threshold of 20, 30 and 40 GeV as a function of the number of minbias events per crossing.

Note that there is a 1 % probability per crossing at ~ 20 GeV for n = 2 events/crossing, ~ 30 GeV for n = 6 events/crossing, and ~ 40 GeV for 9 events per crossing. Therefore, if the present model has any validity, triggering at moderate to high luminosity in CMS on low missing Et will not be particularly useful in SUSY and other searches.

The distribution in the total Et of the crossing for n = 2, 5, 10 and 20 events per crossing is given in Fig.8. Note the rapid increase in the high Et tail at fixed threshold as n increases.

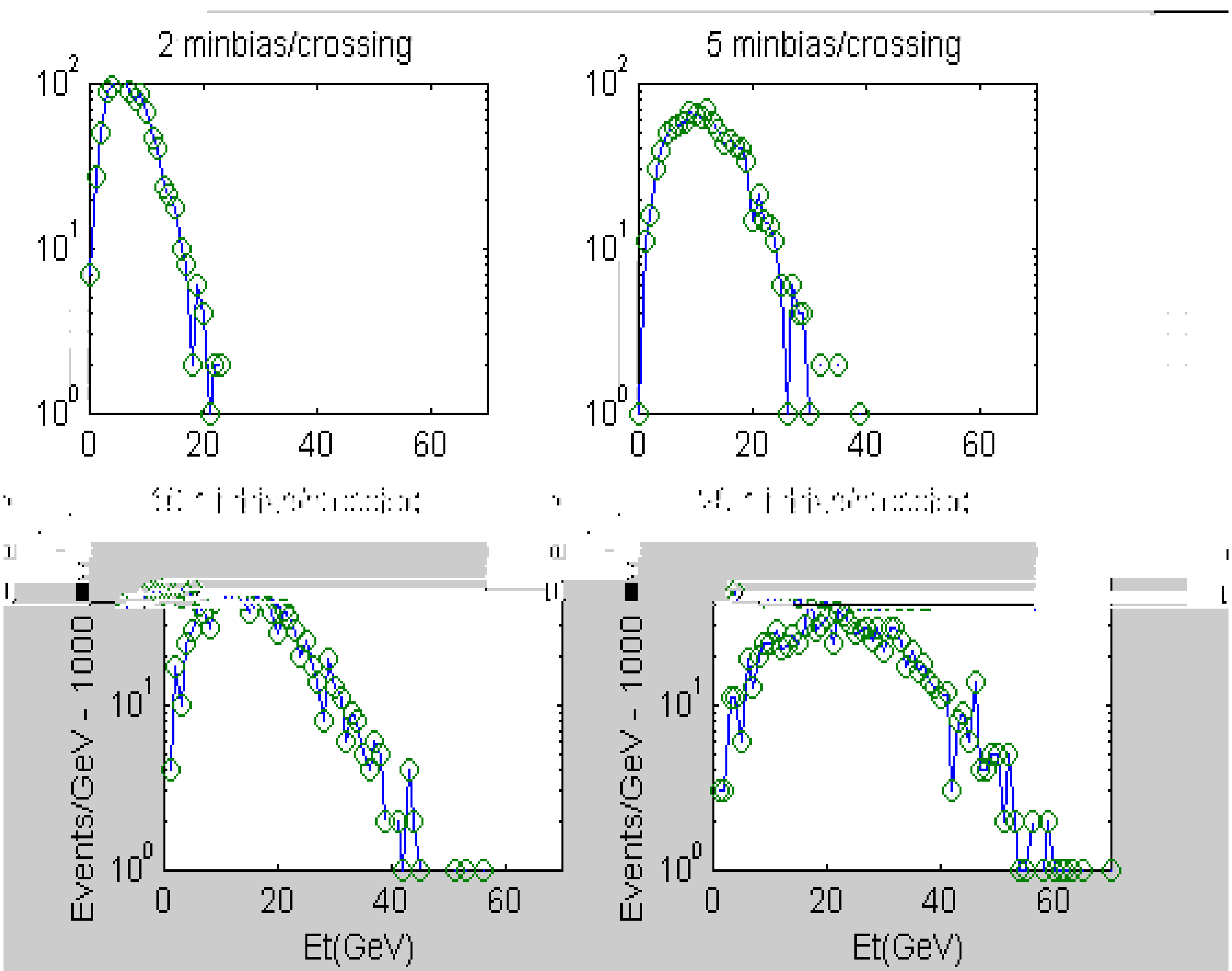

Figure 8: Distribution of total transverse energy in a beam crossing, Et, for a) 2 events/crossing, b) 5 events/crossing, c) 10 events/crossing and d) 20 events/crossing.

Data from Run I of D0 [5] display similar behavior. In Fig. 9 is shown the probability per crossing to pass a threshold of 35 GeV for D0 trigger data with from 1 to 9 events/crossing. A sharp rise with n is seen, similar to that observed in Fig.7. However, for n = 1 event per crosing, the mean Et is ~ 10 GeV with a r.m.s. of 5.2 GeV. The r.m.s. divided by the mean is roughly the same as in the present study, but the value of Et for 1 event is almost twice for D0 as it is for this study. Given the extremely simplified model used in the present study and the large number of experimental effects left out, this disparity is , perhaps, not surprising.

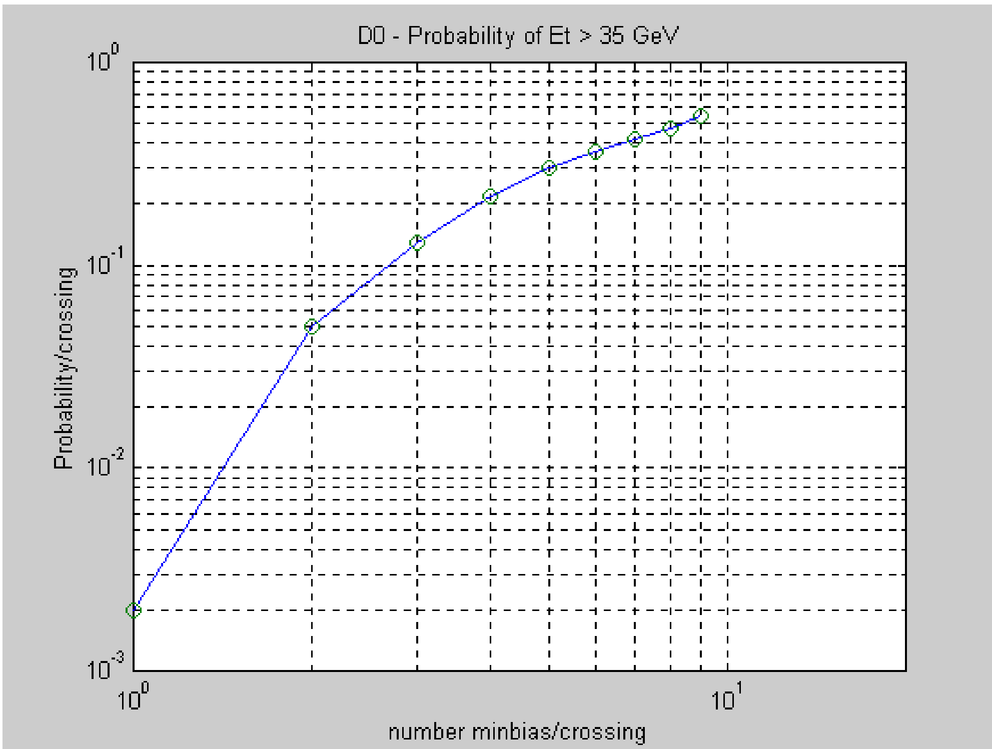

Figure 9: Do data on the probability to exceed a 35 GeV threshold in a crossing as a function of the number of events per crossing.

Conclusions

The transverse energy in a beam bunch crossing induced by truncation of the angular coverage and by calorimetric energy resolution has been studied. For low LHC luminosity, with 1 event per crossing there is ~ 5 GeV transverse energy on average, with a 1% chance to exceed a threshold of 12 GeV for the crossing. The mean Et increases as the square root of n, with a constant r.m.s./mean. At a luminosity with 20 events/crossing, there is a 1% chance per crossing to pass a missing Et cut of 40 GeV.

The effect of placing cuts on the entries put into the Et global sum was studied. An angular restriction of $|y| < 3$ and 2 was compared to the basic $|y| < 5$ cut. Assuming that poorly measured particles were at fault, a cut of E > 10 and 20 GeV was also made on single pions. Assuming that low Pt entries were fluctuating, a cut of Pt > 1.0 and 2.0 GeV on single particles was studied. None of these cuts made any significant improvement in the Et distribution of a crossing in the case of 20 events per crossing. The distribution seems to be almost “holographic”; no matter how it is cut the same distribution, mean and r.m.s. is obtained. Clearly, more incisive cuts, perhaps sorting offline on the primary vertex, must be studied.

References

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4. Review of Particle Physics, 3,(1998)

5. A. Boehnlein, private communication